AD-A134 988 APPLICATION OF RAPIDLY SOLIDIFIED ALLOYS(U) PRATT AND WHITNEY AIRCRAFT GROUP WEST PALM BEACH FL GOVERNMENT PRODUCTS DIV A R COX ET AL. AUG 78 PWA-FR-10754 1/1

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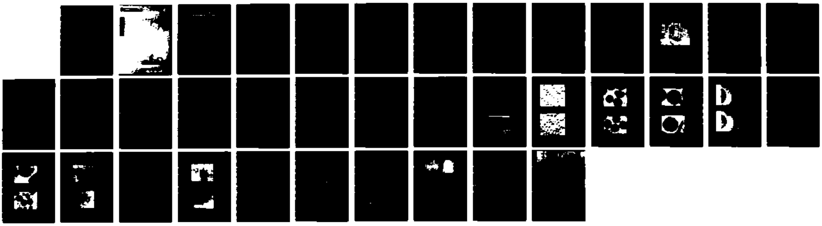

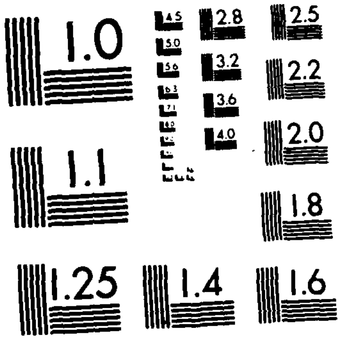

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AD-A134 988

APPLICATION OF RAPIDLY SOLIDIFIED ALLOYS

A. R. Cox
United Technologies Corporation
Pratt & Whitney Aircraft Group
Box 2691, West Palm Beach, Florida 33402

August 1978
Quarterly Report for Period 1 May 1978 through 1 August 1978

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER FR-10754	2. GOVT ACCESSION NO. A134 988	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) APPLICATION OF RAPIDLY SOLIDIFIED ALLOYS		5. TYPE OF REPORT & PERIOD COVERED Quarterly Report 1 May 1978 — 1 August 1978
		6. PERFORMING ORG. REPORT NUMBER FR-10754
7. AUTHOR(s) A. R. Cox T. D. Tillman R. J. Patterson		8. CONTRACT OR GRANT NUMBER(s) F33615-76-C-5136
9. PERFORMING ORGANIZATION NAME AND ADDRESS United Technologies Corporation Pratt & Whitney Aircraft Group Government Products Division Box 2691, West Palm Beach, Florida 33402		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced-Research Projects Agency 1400 Wilson Boulevard Arlington, Virginia 22209 (Dr. E. C. vanReuth)		12. REPORT DATE August 1978
		13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Air Force Materials Laboratories Wright-Patterson Air Force Base, Ohio 45433 (Mr. A. Adair)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release, Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Powder Metallurgy, Rapid Solidification, Centrifugal Atomization, Convective Cooling, Aluminum Alloys, Iron Alloys

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program is being conducted for the purpose of applying the principle of rapid solidification to aluminum and iron alloy powders and subsequent development of stronger alloy compositions for fan blade application (Al alloys) and higher speed bearing material (Fe alloys). Centrifugal atomization and forced convective cooling are being used to produce the fast cooled powder.

During this report period, adaptation of the RSR process to aluminum and iron systems was begun. Both Al and Fe alloys were produced and the Fe alloys were consolidated by direct extrusion. Heat treat study and hardness testing were used for preliminary evaluation of iron alloys.

SUMMARY

This program is being conducted for the purpose of applying the principle of rapid solidification to aluminum and iron alloy powders and subsequent development of stronger alloy compositions for fan blade application (Al alloys) and higher speed bearing material (Fe alloys). Centrifugal atomization and forced convective cooling are being used to produce the fast cooled powder.

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SECTION I

INTRODUCTION

Rapid solidification of metal alloys has shown that distinct and dramatic changes in microstructure and crystal form can be attained beyond those possible by any known method of conventional solidification. These results are recognized by experts throughout the field of metallurgy as a means to achieve major improvements in metal strength, environmental compatibility, electrical properties, etc. Through the use of fast cooling, the following appears to be eminently possible: (1) stronger and more corrosion resistant steels because of improved homogeneity and (2) a new breed of aluminum, copper, and nickel alloys because of improved secondary phase dispersion.

An ARPA sponsored program with the Pratt & Whitney Aircraft Group, Government Products Division (P&WA/Florida), has shown that by using the P&WA RSR process and equipment, it is possible to achieve rapid solidification in spherical powder under conditions which depict steady-state operations commensurate with production rates in excess of 1400 lb/hr. Further, this program has demonstrated that concurrent high product quality can be achieved and the resulting powder metal is in a form which can be readily handled and processed into useful shapes for subsequent application. No other method known to achieve similar rates of solidification can lay claim to these combined achievements.

The program has gone even further since it has demonstrated that controlled, rapid solidification can lead to a microcrystalline form, a condition which could possibly point the way to alloy homogeneity never before considered possible. It has also shown that a central rotary source can be used for liquid metal atomization into powder particles of sizes commensurate with average particle cooling rates of 10^5-10^6°K/sec.

This program is a modification to the Advanced Research Project Agency (ARPA) sponsored work which is directed toward superalloy development. Its purpose is to expand the scope of work in the field of rapid solidification from the exclusive study of superalloys to a study of aluminum, and iron base alloys. The specific objectives of this added effort are the development of an improved aluminum alloy suitable for V/STOL-A fan blades and an improved iron alloy suitable for rolling element bearings for advanced aircraft powerplants.

The program is a 36-month effort which begins with adaptation of the rapid solidification rate process to Al and Fe alloy systems and terminates with a payoff analysis of new materials as adapted to V/STOL-A and F100 advanced engine derivative requirements. This is the first technical report and covers the first through the third months of the program. It deals with adaptation of RSR processing to Al and Fe systems and the subsequent evaluation of these alloys.

SECTION II

POWDER MECHANICS

Pratt & Whitney Aircraft has constructed a scaled down RSR powder device, designated AGT 500000 and shown in Figure 1. It is being used to produce rapidly solidified powder for this program. The new unit is similar to AGT 400000 (the rig now used for superalloy rapid solidification studies). The AGT 500000 device is based on vacuum (or inert gas) induction melting of small charges of metal (up to 14 lb based on iron) and centrifugal atomization from a central, high speed rotary atomizer, Figure 1.

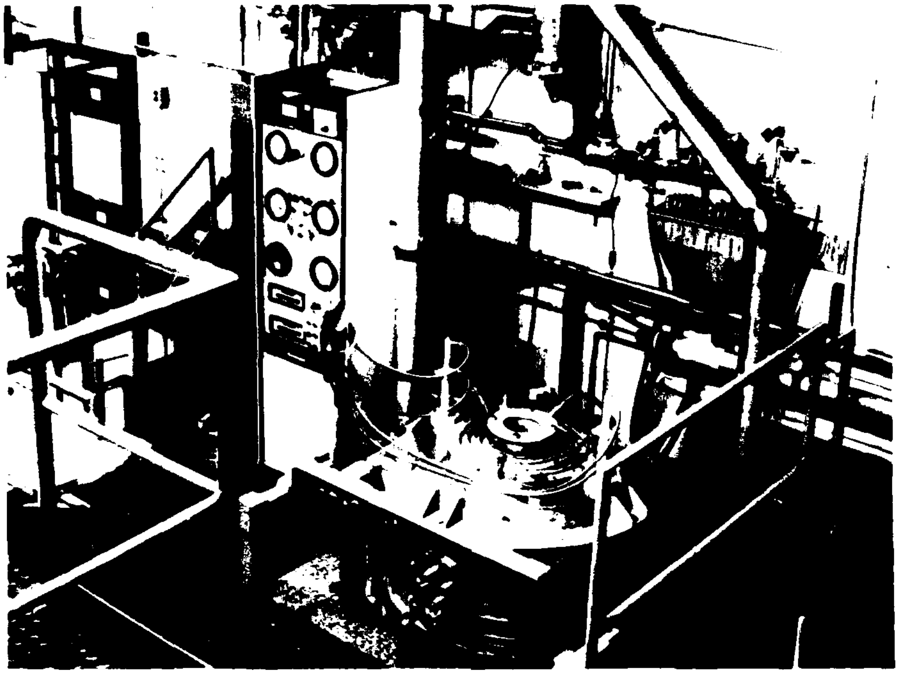

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Figure 1. AGT 500000 Laboratory Scale Rapid Solidification Rig

Forced gas (helium) convective cooling is used to produce the desirable rapid solidification with resulting spherical particles, as opposed to splats generated by conductive cooling. Rotary atomizer design, speed, and melt superheat control particle size, velocity, and trajectory; with the main factors controlling rapid solidification being the heat transfer coefficient and particle size.

With respect to heat transfer, our analytical models show that film heat transfer coefficients on the order of 2×10^6 Btu/ft²/hr/°F (14.7×10^6 cal/cm²/sec/°C) are indicative of infinity for particles greater than 20 microns in diameter. Forced convection of the type used in the AGT 500000 rig can achieve film coefficient values about two orders of magnitude less than this ideal case.

During this report period, effort was directed toward characterization of Al powder made in the AGT 500000 device. Iron base powder will be characterized at a later date. Runs made in the AGT 500000 device have been designated "XSR" to distinguish them from runs made in the larger AGT 400000 device used in the RSR program. Figure 2 presents partial sieve analyses of aluminum alloy 7075 made under RSR conditions; a Co-modified 7075, XSR 33; and of a typical

RSR size distribution for nickel base superalloys, shown for comparative purposes. Size analysis of the aluminum powder finer than −140 mesh was not conducted since that fraction is generally retained for other studies, such as consolidation and extrusion. It should be noted that mechanical failure prevented completion of the XSR run, resulting in the generation of a substantial amount of material above −140 mesh as the turbine speed decreased from the desired operating point of 35,000 rpm. This, of course, also implies that a smaller yield of −140 mesh material was obtained than would normally occur.

Figure 3 presents the maximum velocity that an Al 2024 particle of a given size may have if the particle is to be completely solidified prior to impact with the wall of the XSR device; the two curves display the effect of different amounts of superheat. Al 2024 was selected for this theoretical study of solidification under RSR/XSR conditions because of the limited availability of thermal data at hand for aluminum alloys at the time of the study, and because the aluminum-copper system has been used by others for the characterization of rapid solidification splat quenching devices.

It is interesting to compare the predictions of Figure 3 with the results presente Figure 2. At 35,000 rpm the tangential velocity of the atomizer is approximately 105 m/sec, at this speed the largest particle of Al 2024 which can completely solidify prior to impact sh be on the order of 85 microns. Larger particles should impact while molten, adhering to th amber wall. Yet, the sieve analysis of XSR 33 indicates that a significant amount of substan rger material was obtained.

Several factors account for this apparent discrepancy: (1) recently acquired thermal data for 7075 indicate that near the melting point the specific heat is only 50 to 60% that of 2024, larger particles of 7075 will solidify before impact, for a given velocity; (2) the XSR melt contained somewhat less superheat than was used for the theoretical work; (3) some of the superheat contained in the melt was lost during the transfer and atomization process (e.g., to the water-cooled atomizer); the theoretical study assumed that particles contained the specified superheat at the time of formation; (4) the graph presents a limit for the sizes of particles which are completely solidified at impact, while in reality, partially solidified particles might be sufficiently solid that they do not adhere to the wall; (5) thermal data for the alloys of interest to this program have not been found for the liquid state, and these properties had to be estimated for the theoretical effort. In this regard, data recently found for pure aluminum suggest that the specific heat of molten materials is somewhat lower than we have estimated, so that cooling rates (and distances required for solidification) resulting from the calculations is probably somewhat conservative; (6) some of the material larger than 140 mesh may have been formed by splashing of the melt as it continued to pour after the turbine drive ceased rotation. Also, as noted earlier, much of the material probably formed as the turbine speed decreased from 35,000 rpm. These particles would not only have velocities lower than 100 m/sec, but from earlier work in the RSR program, they would also be larger. Simple extrapolation of the curves of Figure 3 suggests that particles at least as large as 650 microns diameter may solidify completely prior to impact when speeds are on the order of 1 m/sec (334 rpm for XSR 33). Indeed, less than 3% of the particulate collected from the run was larger than 40 mesh (425 microns).

Theoretical and empirical efforts were also undertaken to attempt to determine the cooling rates of materials produced in the XSR device. The theoretical work for mean cooling rates is presented in Figure 4 for systems of interest to this program; the curve previously published for IN 100 is shown for comparison. As noted for the previous figure, the data recently acquired for the specific heat of 7075 and for the probable behavior of the specific heat above the liquidus would suggest that the mean cooling rate of 7075-type alloys is probably somewhat better than the curves presented for both 2024 and pure aluminum, the specific heats of which are similar. How well the cooling rates predicted for 347 stainless steel correlate with those which might be obtained for compositions contemplated for bearing elements is not presently known.

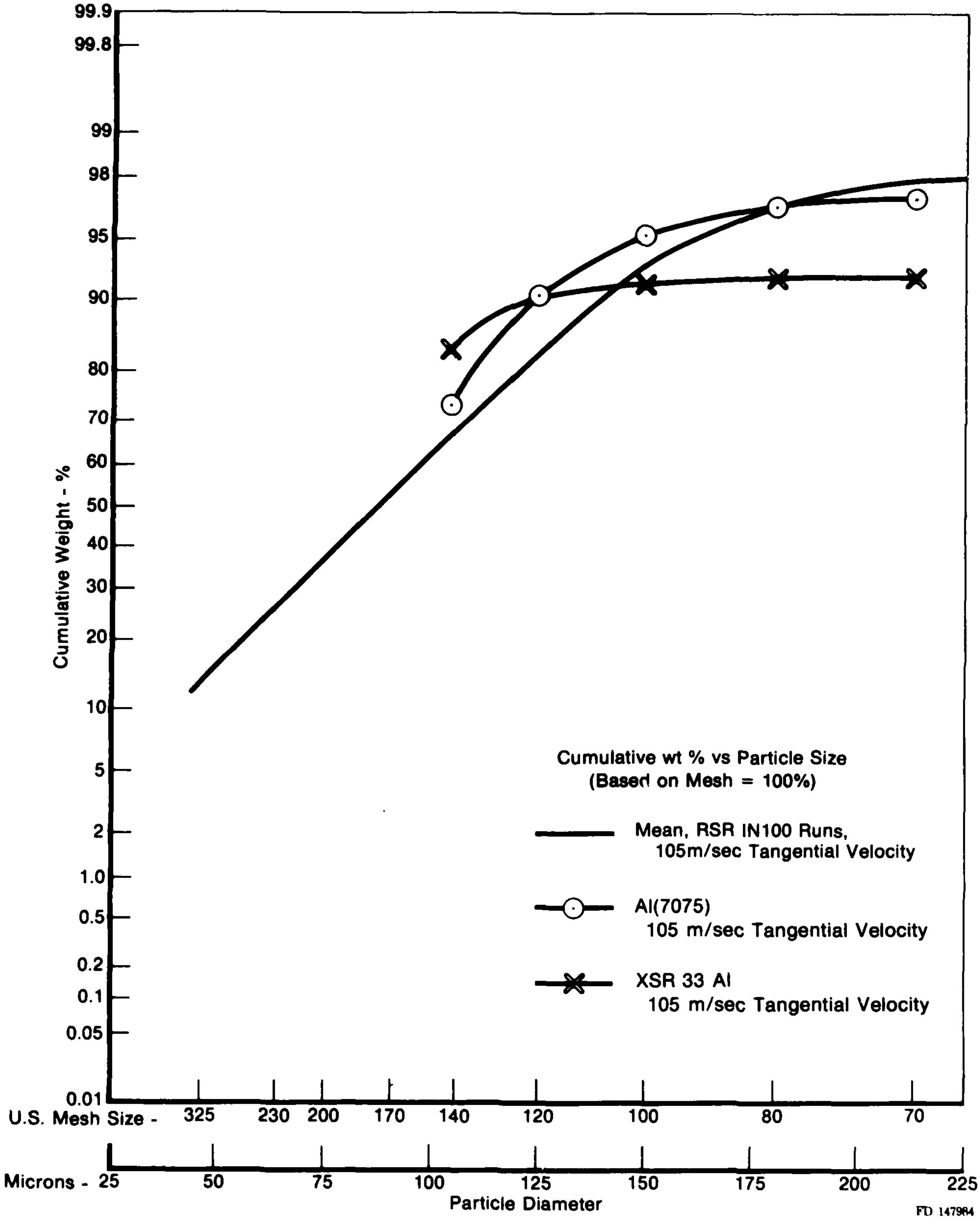


Figure 2. Partial Sieve Analysis of XSR/RSR Powder

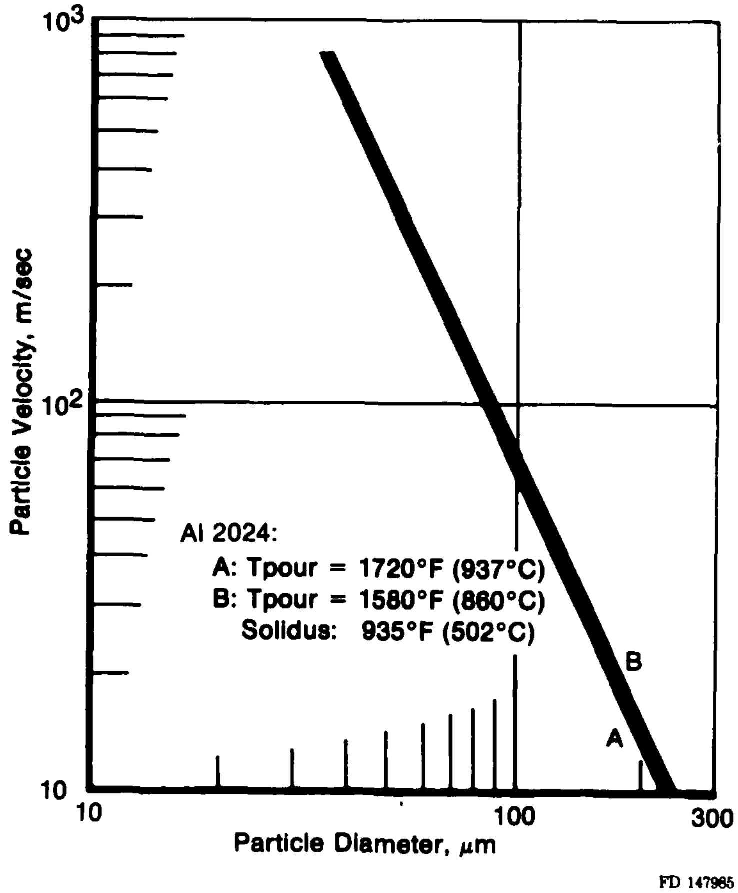


Figure 3. Particle Size Completely Solidified Before Impacting XSR Tank Wall as Function of Speed

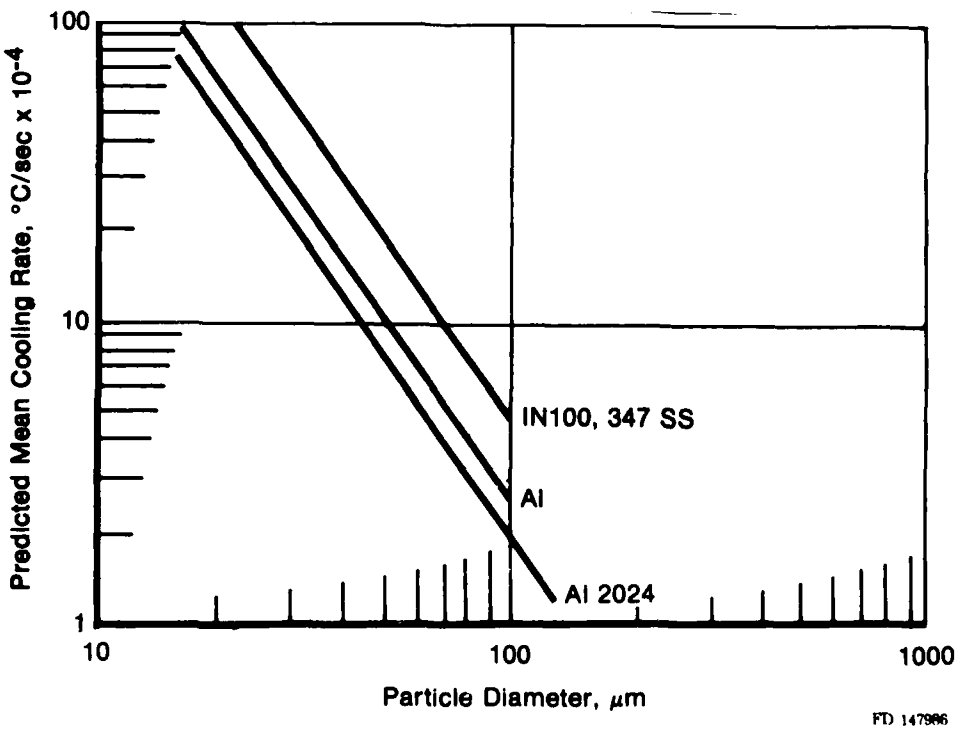


Figure 4. Predicted Mean Cooling Rates vs Particle Size (XSR/RSR)

The empirical side of this effort has not fared as well, and no results can be presented at this time. First, as reported by Horwath and Mondolfo[1] for the Al-Cu system, and as discussed by Holiday[2] *et al* for some of the nickel base superalloys, the secondary dendrite spacing commonly used for empirical determination of cooling rate has been found to depend not only upon cooling rate of the material but also upon its specific chemistry. Hence, while the method may allow the relative comparison of cooling rates for particles of a specific composition, the technique does not appear to allow the independent determination of absolute rates. Second, metallographic analysis of particles of the steel and aluminum alloys prepared to date has yielded structures which are not classically dendritic, so the technique has not even allowed the determination of relative rates for these alloys. An attempt to obtain a feeling for the relative rates by microprobe determination of the variation of segregation within particles of different sizes is also futile, since the beam size of the microprobe is at least as large as any such segregation.

[1] Horwath, J. A., L. F. Mondolfo; "Dendritic Growth"; ACTA Met, Vol 10, 1962, pp. 1037-1042.
[2] Holiday, P. R. et al; Rapid Solidification Effects on Alloy Structures; *Rapid Solidification Processing*, Claitor's Publishing Division, Baton Rouge, 1978.

SECTION III

MATERIAL SELECTION

Two matrices, one each for Al and Fe systems, were formulated as listed in Table 1 and selections were made for production of vacuum melt ingots suitable for conversion to powder.

TABLE 1. FIRST Al AND Fe MATRIX

*Al Matrix**					
		Cobalt			
Zn-		*0.8*	*1.6*	*2.4*	*3.2*
5.6		X	X		X
7.0		X			X
8.4			X		
9.8					
*Fe Matrix**					
		Molybdenum			
Cr	*C*	*2*	*4*	*6*	*8*
	0.8		(M-50)		
4	0.8				
9	0.8				
	0.95				
14	0.8				
	1.1	(EX-0007) X		X	
19	0.8				
	1.25	X			X

*Amounts are in weight %.

In the aluminum matrix, Zn and Co were varied using similar or greater amounts of Zn than specified in 7075 and varying Co from 0.8 wt% to 3.2 wt%. The Co forms a Co_2Al_9 compound which, when present in an appropriate dispersion, should control grain size since it is insoluble at the solutioning temperatures of the Zn, Mg, and Cu rich phases. Increasing Zn will provide a greater amount of second phase available for precipitation hardening. One heat of 7075 was run as a control to assess the effects of rapid solidification on a high-strength, age-hardenable alloy.

Four selections were made from the Fe matrix which contain high Cr, 14 and 19 wt%, and varying amounts of Mo. One alloy similar to EX-00007 was included for comparison with other work being done on this alloy.

Both Fe and Al experimental alloy samples in the form of buttons weighing 2 oz (60g) for Fe and 1 oz (30g) for Al have been produced. These alloys, listed in Table 2, have been treated by electron beam (EB) surface irradiation to produce macroregions depicting rapid solidification. Difficulty was encountered in melting elements to produce the Al buttons. Two methods were tried, a tungsten arc melting device used to make small experimental samples and an induction furnace with melting taking place in a small ceramic crucible. Neither method was successful in completely alloying all elements. Additional trials will be made using the induction furnace and forced mixing to ensure complete alloying of all elements. Iron alloys were produced in the arc melting device and no problems were encountered in obtaining proper alloying.

TABLE 2. EXPERIMENTAL ALLOY COMPOSITION*

Identification Number	C	Mo	Cr	V	Mn	Si	Fe
BI-1	0.8	2.0	4.0	1.0	—	—	Bal
BI-2	0.8	4.0	4.0	1.0	—	—	Bal
BI-3	0.8	8.0	4.0	1.0	—	—	Bal
BI-4	0.8	2.0	9.0	1.0	—	—	Bal
BI-5	0.8	6.0	9.0	1.0	—	—	Bal
BI-6	0.95	2.0	9.0	1.0	—	—	Bal
BI-7	0.95	6.0	9.0	1.0	—	—	Bal
BI-8	0.8	6.0	14.0	1.0	—	—	Bal
BI-9	1.1	2.0	14.0	1.0	—	—	Bal
BI-10	1.1	6.0	14.0	1.0	—	—	Bal
BI-16A	1.1	2.0	14.0	1.0	0.2	0.2	Bal
BI-16B	1.1	2.0	14.0	1.0	0.2	—	Bal
BI-17A	1.1	6.0	14.0	1.0	0.2	0.2	Bal
BI-17B	1.1	6.0	14.0	1.0	0.2	—	Bal
BI-18A	1.25	2.0	19.0	1.0	0.2	0.2	Bal
BI-18B	1.25	2.0	19.0	1.0	0.2	—	Bal
BI-19A	1.25	8.0	19.0	1.0	0.2	0.2	Bal
BI-19B	1.25	8.0	19.0	1.0	0.2	—	Bal

Note: BI 5.6% Zn, 0.8% Co, 2.5% Mg, 1.0% Cu, Bal Al
*wt.%

SECTION IV

CONVERSION AND CONSOLIDATION

Twenty powder runs were attempted during the first quarter to gain experience in operation of AGT 500000 and to provide material for evaluation. Atomizer speed, nozzle diameter, cup radius, and pour temperature were varied to assess their impact on powder yield. Some difficulties were encountered and are under investigation to assure the best possible yield of −140 mesh (105 micron) powder. Tables 3 and 4 give material compositions and pertinent information and comments on the twenty powder conversions attempted.

XSR-24 was the first steel conversion attempted in a redesigned high temperature furnace with the result being no metal flow due to nozzle plugging, presumably due to the nozzle temperature being too low. This furnace has been redesigned again and incorporates a separate transfer tube heater and should be operational in the second quarter of this contract.

Five RSR steel conversions were attempted with four being successful; the one failure being due to a run abortion after observing abnormal appearance of metal leaving the cup. Initial indications are that iron base alloys must be converted at a lower superheat than nickel base alloys to achieve stable melt flow on the atomizer rotor.

Fourteen XSR A1 conversions were attempted with ten being successful and six having yields in excess of 50%. Two runs XSR-26 and 28 did not pour due to a nozzle blockage and insufficient superheat respectively.

Both the Al and Fe alloys were screened in air through −80 mesh and −140 mesh screens. The −140 mesh powder was then outgassed, and the cans were filled and sealed under vacuum. Cans were fabricated of 6061 for the Al powder and 304 stainless steel for the Fe powder.

Three extrusion temperatures 1750°F (954°C), 1850°F (1010°C), and 2000°F (1093°C) were used on the four Fe compositions (three cans each). Reduction ratio was 15:1 through a ceramic insert in a steel die with a 90° included angle steel cone being used in front of the die. Final diameter was a nominal 0.75 in. (1.9 cm). Table 5 gives particulars on each extrusion.

Six Al extrusion cans were prepared, three cans of XSR 19, 20, and 21 combined, and one can each of XSR 23, 25, and 27. These cans have been shipped to AFML and should be extruded in the second quarter of this contract.

TABLE 3. POWDER RUNS ATTEMPTED DURING 1ST QUARTER

XSR-Run No.	*Alloy*	*Nozzle Dia in. (cm)*	*Cup Speed (rpm)*	*Cup Radius in. (cm)*	*Nozzle* Temp °F (°C)	*Melt* Temp °F (°C)	*Alloy Melting* Point °F (°C)	*Percent*[2] Yield	Comments
XSR-19	VM 578	0.125 (0.318)	24K	3.125 (7.938)	1290 (699)	1620 (882)	1180 (638)	36.4	
XSR-20	VM 578	0.125 (0.318)	24K	3.125 (7.938)	1180 (638)	1460 (793)	1180 (638)	33.9	
XSR-21	VM 578	0.125 (0.318)	24K	3.125 (7.938)	1100 (593)	1400 (760)	1180 (638)	40.7	
XSR-22	VM 581	0.125 (0.318)	24K	3.125 (7.938)	1160 (627)	1430 (777)	1160 (627)	0	No helium flow
XSR-23	VM 581	0.100 (0.254)	24K	3.125 (7.938)	1170 (632)	1490 (810)	1160 (627)	75.2	
XSR-24	VM 592	0.125 (0.318)	24K[1]	5.250 (13.335)	—	2620 (1438)	2600 (1427)	0	Solidified in Nozzle
XSR-25	VM 582	0.100 (0.254)	30K[1]	3.600 (9.144)	1220 (660)	1530 (832)	—	74.8	
XSR-26	VM 582	0.100 (0.254)	24K[1]	3.125 (7.938)	1180 (638)	1540 (1838)	1185 (641)	0	Nozzle blocked
XSR-27	VM 583	0.125 (0.318)	24K	3.125 (7.938)	—	1510 (821)	1180 (638)	46.0	
XSR-28	VM 583	0.125 (0.318)	24K	3.125 (7.938)	1180 (638)	1350 (732)	1180 (638)	0	Solidified in Nozzle
XSR-29	VM 595	0.100 (0.254)	24K	3.125 (7.938)	1210 (654)	1410 (766)	1180 (638)	72.7	
XSR-30	VM 595	0.100 (0.254)	24K	3.125 (7.938)	1230 (666)	1500 (816)	1170 (632)	83.8	
XSR-31	VM 595	0.100 (0.254)	24K	3.125 (7.938)	1230 (666)	1495 (813)	1200 (649)	76.8	
XSR-32	VM 596	0.100 (0.254)	30K[1]	3.600 (9.144)	1240 (671)	1505 (818)	1170 (632)	0	Stopper rod did not release
XSR-33	VM 615	0.100 (0.254)	35K[1] *	3.600 (9.144)	1240 (671)	1500 (816)	1160/1190 (627/643)	51.3	
RSR-199	VM 592	0.158 (0.401	24K	5.250 (13.335)	2400 (1316)	3000 (1649)	2650 (1454)	0	Nozzle plugged
RSR-200	VM 592	0.158 (0.401)	24K	5.250 (13.335)	2400 (1316)	2900 (1593)	2650 (1454)	>50	
RSR-201	VM 593	0.158 (0.401)	24K	5.250 (13.335)	2450 (1343)	2900 (1593)	2650 (1454)	>50	
RSR-202	VM 594	0.158 (0.401)	24K	5.250 (13.335)	2350 (1288)	2900 (1593)	2650 (1454)	>50	
RSR-203	VM 591	0.158 (0.401)	24K	5.250 (13.335)	2350 (1288)	2800 (1538)	2650 (1454)	>50	

*Bearing failure caused speed decay from initial 35K to zero during run, accounting for poor yield of −140 mesh powder.
[1]35K turbine run at indicated rpm.
[2]Percent yield-wt of −140 mesh/wt charged.

TABLE 4. COMPOSITION OF ALLOYS CONVERTED TO POWDER*

Powder Run No.	VM No.	Zn	Co	Al	Mg	Cu	Cr	Mo	C	V	Fe
XSR 19 (7075)	578	5.6	—	Bal.	2.5	1.6	0.3				
XSR 20 (7075)	578	5.6	—	Bal.	2.5	1.6	0.3				
XSR 21 (7075)	578	5.6	—	Bal.	2.5	1.6	0.3				
XSR 22	581	5.6	0.8	Bal.	2.5	1.0					
XSR 23	581	5.6	0.8	Bal.	2.5	1.0					
XSR 24	592						14.0	6.0	1.1	1.0	Bal.
XSR 25	582	5.6	1.6	Bal.	2.5	1.0					
XSR 26	582	5.6	1.6	Bal.	2.5	1.0					
XSR 27	583	5.6	3.2	Bal.	2.5	1.0					
XSR 28	583	5.6	3.2	Bal.	2.5	1.0					
XSR 29	595	7.0	0.8	Bal.	2.5	1.0					
XSR 30	595	7.0	0.8	Bal.	2.5	1.0					
XSR 31	595	7.0	0.8	Bal.	2.5	1.0					
XSR 32	596	7.0	3.2	Bal.	2.5	1.0					
XSR 33	615	7.0	3.2	Bal.	2.5	1.0					
RSR 199	592						14.0	6.0	1.0	1.0	Bal.
RSR 200	592						14.0	6.0	1.1	1.0	Bal.
RSR 201	593						19.0	2	1.25	1.0	Bal.
RSR 202	594						19.0	8	1.25	1.0	Bal.
RSR 203	591						14.0	2	1.1	1	Bal.

*wt %

TABLE 5. IRON ALLOY EXTRUSIONS

Identification No.	Extrusion Temp °F	(°C)	Tonnage*
200A	1850	(1010)	500
201A	1850F	(1010)	500
202A	1850	(1010)	510
203A	1850	(1010)	475
200B	2000	(1093)	600
201B	2000	(1093)	450
202B	2000	(1093)	430
203B	2000	(1093)	400
200C	1750	(954)	540
201C	1750	(954)	500
202C	1750	(954)	570
203C	1750	(954)	560

*Breakthrough pressure

SECTION V

MATERIAL EVALUATION

ALUMINUM ALLOYS

Due to difficulty encountered in producing Al buttons only one sample B1 was treated by electron beam (EB) surface irradiation. This sample was given six different weld passes. Weld depths ranged from 0.03 in. (0.08 cm) to 0.053 in. (0.13 cm). Additional effort in this area will be provided using the induction furnace for melting and EB welding at lower power settings to produce shallower penetration and resulting faster cooling. Figure 5 shows a representative weld and resulting microstructure.

Examination of XSR Al powder revealed a rough surface as compared to RSR Al powder shown in Figure 6. The rough surface on XSR powder is due to a smaller chamber and multiple collisions with chamber walls and other powder particles. Microscopic examination of powder cross-section revealed a two-phase structure which can be described as cellular. Powder produced in the RSR rig is, as expected, very similar microstructurally to XSR Al powder. (See Figures 7 and 8.)

IRON ALLOYS

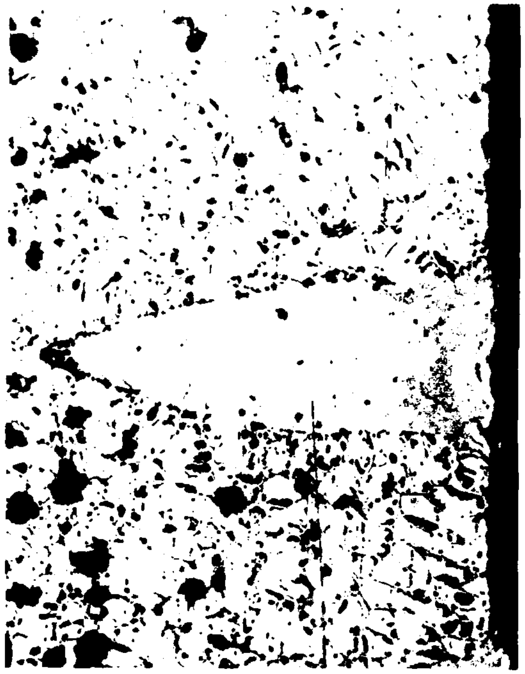
EB weld parameters were varied to produce different levels of penetration in iron alloy samples. Penetration varied from approximately 0.004 in. (0.010 cm) to 0.010 in. (0.025 cm), and machine parameters producing weld penetration of 0.004 in. (0.010 cm) and 0.008 in. (0.020 cm) were selected for welding of all iron alloys. Figure 9 shows representative structures resulting from EB welding using the selected penetration levels. Hardness readings were taken on buttons BI-2 through 10 and BI 16-19 and are presented in Table 6. Buttons 16-18A were given a solution cycle of 2050°F (1121°C) for 10 minutes followed by an oil quench. Hardness measurements were taken and are also presented in Table 6. Hardness obtained on 16-18A, R_c 61.5-64.2, were comparable to hardnesses obtained on heat treated extrusions from RSR powder. Future effort will be directed toward heat treatment of selected buttons from Table 6 and melting additional alloys with compositional variations over a wider range than those examined in this quarter.

Examination of iron alloy powder particles revealed an occasional cellular structure and a predominantly fine structure which could not be classed as either cellular or dendrite. (See Figure 10.)

Iron alloy extrusions were examined metallographically and found to have a uniform structure with a fine carbide dispersion and a grain size of ASTM 9-11 or smaller. Figure 11 shows representative structures of 202C and 203B.

Extrusions were cut up and the sections stamped with identification numbers. The sections were then heat treated and hardness readings taken. The identification scheme used and particulars of various heat treatments are given in Table 7. Figure 12 shows a representative structure of a steel alloy which has been solutioned at 2100°F (1148°C) for 10 minutes and quenched, note uniform carbide dispersion.

All samples were quenched into a salt brine dry ice mixture from the solution temperature, surface ground to remove de-carburized layer and hardness readings taken. Table 8 lists the hardness readings obtained.

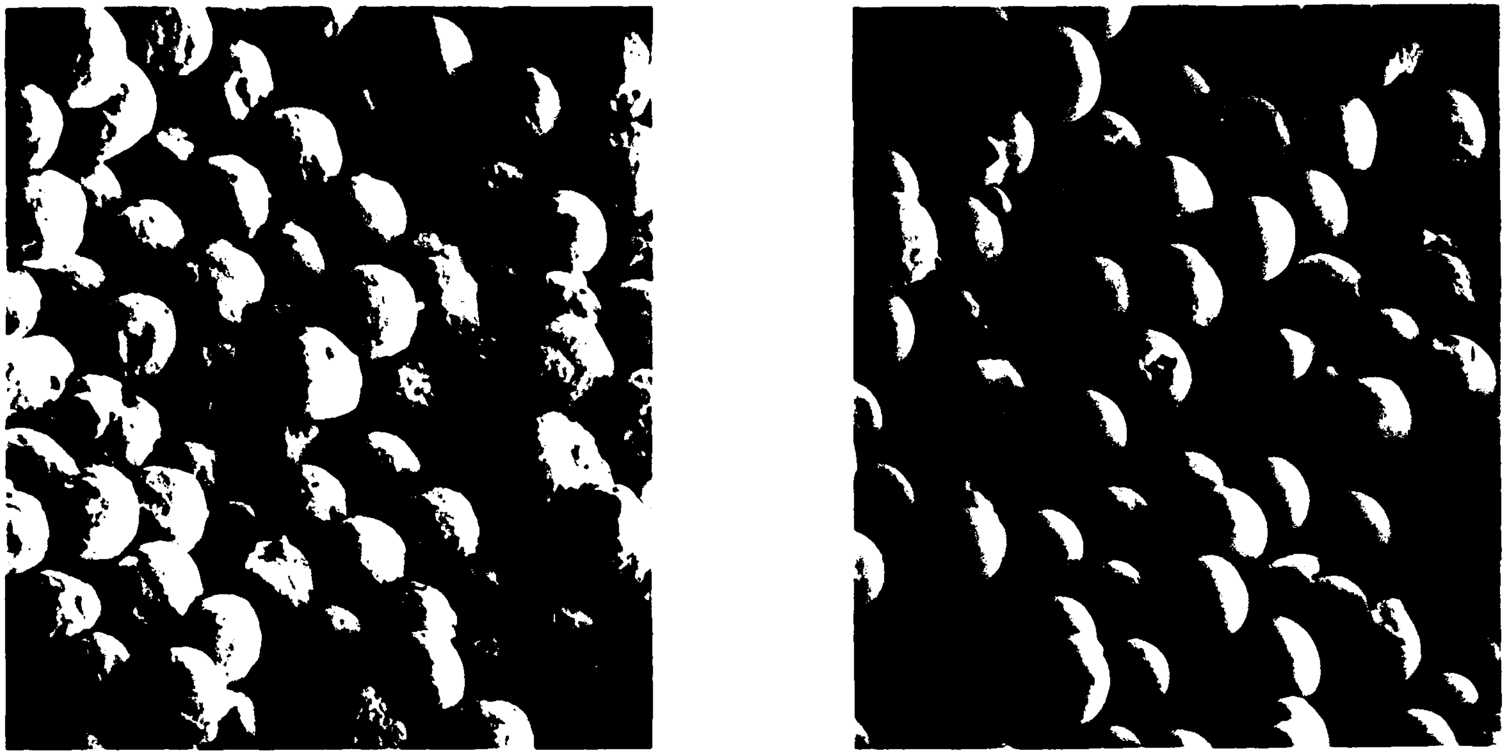


Mag: 1000X, Etch Keller's

FAM 88979

FD 147987

Figure 5. B-1, EB Weld No. 4, Penetration 0.046 in. (0.117 cm)



Mag: 100X FAM 88844

a. XSR

Mag: 100X FAM 88839

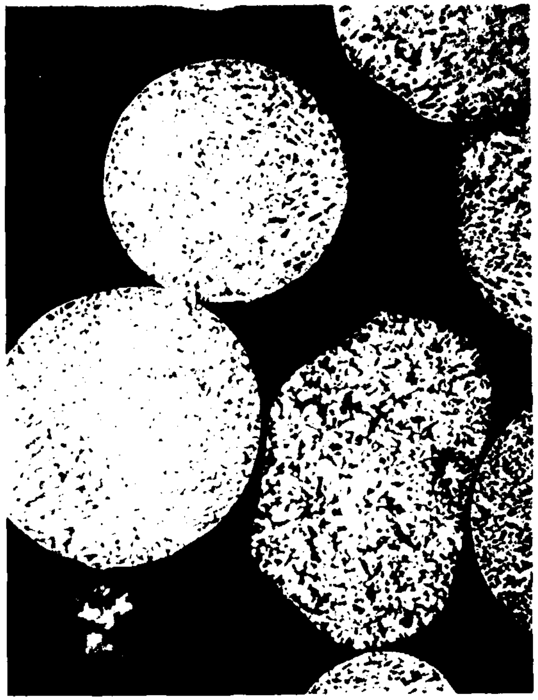
b. RSR

FD 147988

Figure 6. Surface Appearance of 90 μm XSR and RSR 7075 Aluminum Powder

Mag: 400X, Etch 20% Keller's FAM 88968

XSR-19



Mag: 400X, Etch 5% Kellers FAM 88975

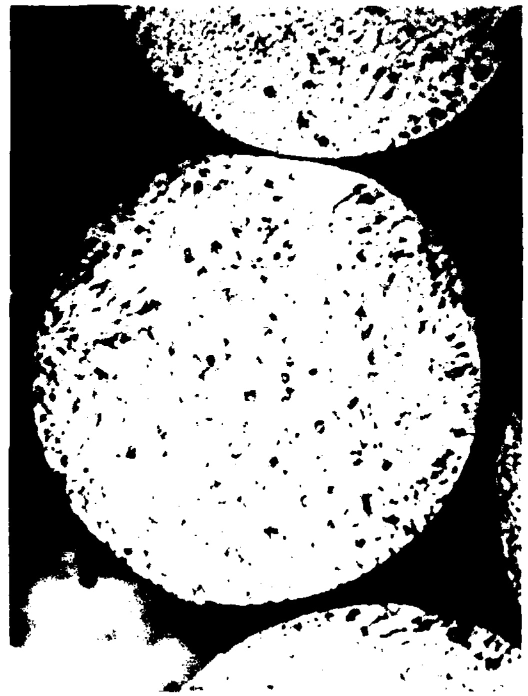
RSR

FD 147989

Figure 7. Microstructure of 90 μm XSR and RSR 7075 Aluminum Powder

Mag: 1000X FAM 88974

XSR-19



Mag: 1000X FAM 88973

RSR

Etch. 20% Keller's

FD 147990

Figure 8. Microstructure of 62 μm XSR and RSR 7075 Aluminum Powder

Mag: 100X Etch Glyceriga FAM 88972

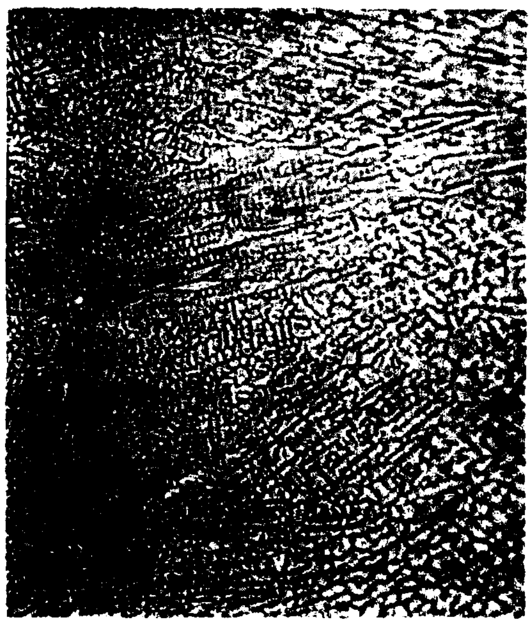
a.

Mag: 1000X Etch Glyceriga FAM 88971

b.

Mag: 100X Etch Glyceriga FAM 88970

c.



Mag: 1000X Etch Glyceriga FAM 88969

d.

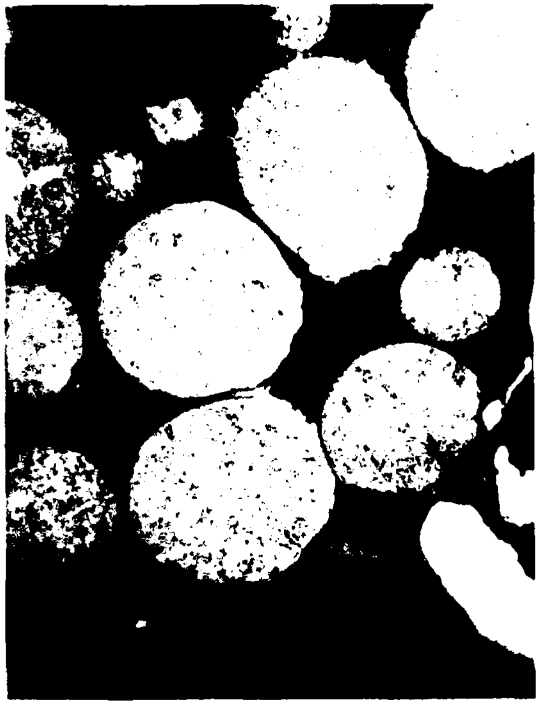
FD 147991

Figure 9. Representative Microstructure of Iron Alloy Buttons, as EB Welded: a and b Penetration of 0.004 in. (0.010 cm); c and d Penetration of 0.008 in. (0.020 cm).

TABLE 6. IRON ALLOY BUTTON HARDNESS[1]

I.D. No.	No. 1 Weld[2]	No. 1 Weld (HT)	No. 2 Weld[3]	No. 2 Weld (HT)
BI-2	62		63	
3	64		62	
4	58		57	
5	50		47	
6	49		47	
7	53		45	
8	38		39	
9	45		46	
10	41		42	
16A	44	62	41	62
16B	46		45	
17A	48	61.5	45	62.5
17B	42		44	
18A	46	63.5	47	64.2
18B	—		—	
19A	81R_b		—	
19B	44		44	

[1] All hardnesses are R_c unless otherwise indicated.
[2] Weld No. 1 penetration approximately 0.004 in. (0.010 cm).
[3] Weld No. 2 penetration approximately 0.008 in. (0.020 cm).



Mag: 400X FAM 88976

Mag: 1000X FAM 88977

-140 Mesh Etch Glyceriga

FD 147992

Figure 10. Microstructure of RSR 200 Iron Alloy Powder

FAM 88980

202C

Transverse

Mag: 1000X
Etch Picral + Nita

FAM 88981

203B

FD 147993

Figure 11. Representative Microstructure of Iron Alloy Extrusions

TABLE 7. FIRST IRON MATRIX EXTRUSION AND HEAT TREAT IDENTIFICATION SCHEME

Matrix No.	*VM No.*	*RSR No.*	*Extrusion No.*
9	591	203	3
10	592	199 + 200	0
14	593	201	1
15	594	202	2

Extrusion Temp. (°F/°C)	*Identification*
1850/1010	A
2000/1093	B
1750/954	C

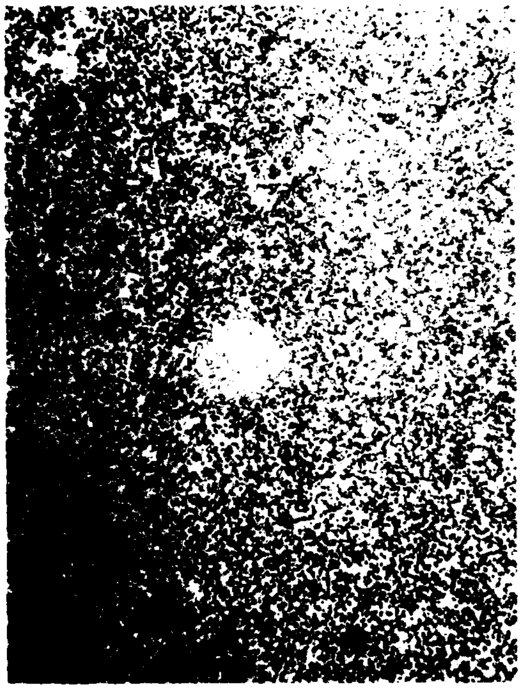
Solution Temp.[1] *(°F/°C)*	*Identification No.*
1800/982	8
1900/1038	9
2000/1093	0
2100/1148	1
2200/1204	2
2300/1260	3
2400/1316	4

Solution Time	*Identification No.*
5 min.	1
10	2
50	3
100	4

Example: Sample No. 3B14; 3- RSR 203, B-2000°F (1093°C) extrusion, 1- 2100°F (1148°C) solution, 4 - 100 min solution

[1]All samples were quenched in a salt brine/dry ice bath.

Transverse Section



Mag: 400X, Etch Glyceriga FAM 88982
201 C

Mag: 1000X, Etch Glyceriga FAM 88983
203C

FD 147994

Figure 12. Representative Microstructures of Iron Alloy Extrusions, Solutioned and Quenched

TABLE 8. HARDNESS OF AS SOLUTIONED STEEL

Sample No.	*Rc*	*Sample No.*	*Rc*	*Sample No.*	*Rc*	*Sample No.*	*Rc*
OA81	—	1A81	31	2A81	—	3A81	49
82	44.7	82	43.9	82	31	82	55.3
83	51	83	54	83	17	83	57
84	34	84	50	84	27.5	84	46.5
OA91	51.5	1A91	53	2A91	32	3A91	58.6
92	59.4	92	57.4	92	32	92	60
93	57	93	58.5	93	25.5	93	57
94	56.8	94	59	94	24	94	58
OA01	53.5	1A01	57.5	2A01	32	3A01	60
02	59.6	02	59.3	02	32.4	02	60.3
03	60	03	58.2	03	21.8	03	36.5
04	39	04	59.4	04	28.6	04	46
OA11	56.4	1A11	61	2A11	31.7	3A11	61
12	60	12	60.5	12	29	12	61.1
13	61	13	59	13	29.2	13	34
14	32.5	14	61	14	29.5	14	49
OA21	58.9	1A21	56.5	2A21	29.5	3A21	53.5
22	42.5	22	50.5	22	29.5	22	40.5
23	28	23	47	23	31	23	39.8
24	30	24	40.5	24	32.5	24	38
OB81	—	1B81	36.8	2B81	—	3B81	47.1
82	44.1	82	45.4	82	—	82	54.6
83	50.5	83	53	83	27	83	57
84	31	84	24.5	84	26.5	84	52
OB91	54	1B91	54	2B91	29.4	3B91	57
92	59.8	92	57.2	92	24.7	92	58
93	57	93	58	93	27	93	56
94	57.5	94	51	94	28	94	56.5
OB01	55	1B01	56.8	2B01	29.8	3B01	60
02	58.5	02	58.6	02	30	02	60.1
03	58.7	03	60.5	03	27	03	50
04	60	04	59	04	26	04	58
OB11	59.8	1B11	61.5	2B11	28.8	3B11	62
12	60	12	60.4	12	25.5	12	59.8
13	59	13	60.4	13	27	13	21.7
14	41	14	59	14	23	14	20
OB21	53.5	1B21	58.5	2B21	28.3	3B21	52
22	41.5	22	46	22	33.5	22	41
23	24.5	23	44	23	22.3	23	32
24	31.5	24	39.5	24	35	24	17
OC81	—	1C81	31	2C81	27.5	3C81	46.4
82	45	82	44	82	28.9	82	55.1
83	51	83	54	83	23.5	83	57
84	35	84	33	84	24.5	84	53.5
OC91	53	1C91	53.8	2C91	29.2	3C91	57
92	58.1	92	57.7	92	30.1	92	60.4
93	54	93	57.5	93	27	93	58
94	35	94	58	94	27.7	94	58
OC01	53.8	1C01	59.2	2C01	28.2	3C01	54.7
02	60	02	58	02	31.1	02	60.3
03	60	03	59	03	27.3	03	61
04	45	04	59.5	04	28.5	04	60
OC11	58	1C11	61.5	2C11	29	3C11	60
12	61	12	59	12	29	12	59
13	59.5	13	59	13	28.2	13	57
14	52	14	59	14	41	14	59
OC21	54	1C21	58.5	2C21	28	3C21	56
22	—	22	41.5	22	32	22	41
23	21	23	46.5	23	25	23	36
24	31.5	24	13	24	33	24	
						3CFHT	61.3

From this data, plots were made of hardness vs solution temperature with varying solution times using the two alloys, 201 and 203. Figures 13 and 14 show these results. Alloy 203 reached the highest hardness using solution temperature of 2050°F (1121°C) for ten minutes, with a maximum hardness attained of 61.1 R_c in the solutioned and quenched state.

Several samples of Alloy 203C were given a heat treatment developed by Marlin-Rockwell Corporation (MRC) a division of TRW, for EX-00007, under contract by P&WA. The full heat treatment used was as follows:

1550°F/15 min→2050°F/10 min/oil quench to black heat then air cool
350°F/2 hr/AC LN_2/2 hr/to room temp.
950°F/3 hr/AC LN_2/2 hr/to room temp.
950°F/3 hr/AC LN_2/2 hr/to room temp.
950°F/3 hr/AC LN_2/2 hr/to room temp.

Fully heat treated hardness on 203C was R_c 61.3 as compared to 62.4 for EX-00007 heat treated by MRC[1] Typical microstructure of 203 CFHT, fully heat treated, is shown in Figure 15.

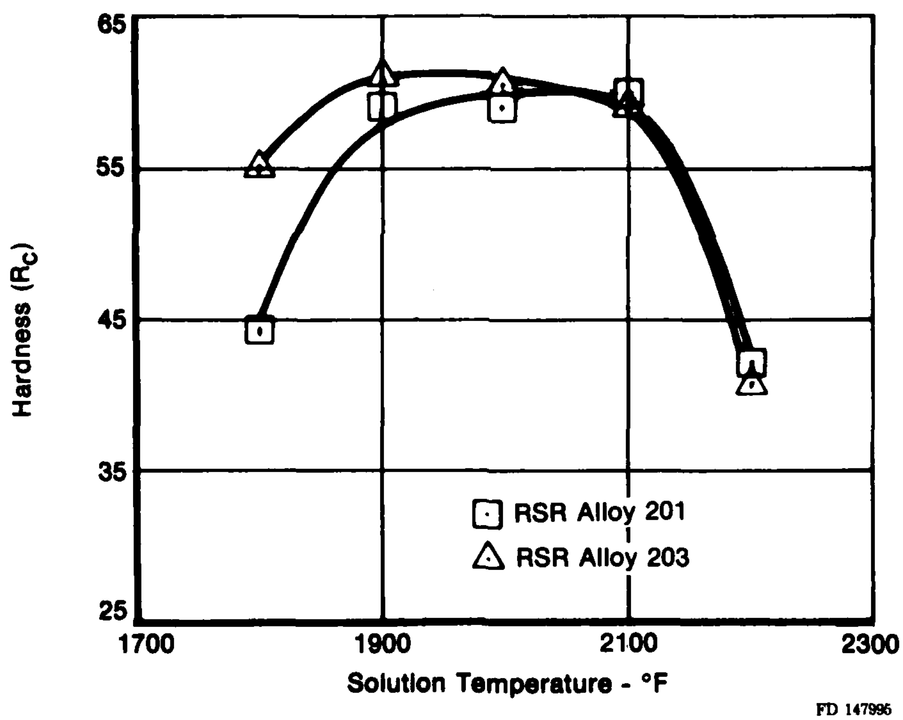


Figure 13. As Quenched Hardness vs 10 Min Solution Temperature

[1] Brown, P. F., J. R. Potts, "Evaluation of Powder Processed Ball Bearings," Report No. AFAPL-TR-77-26.

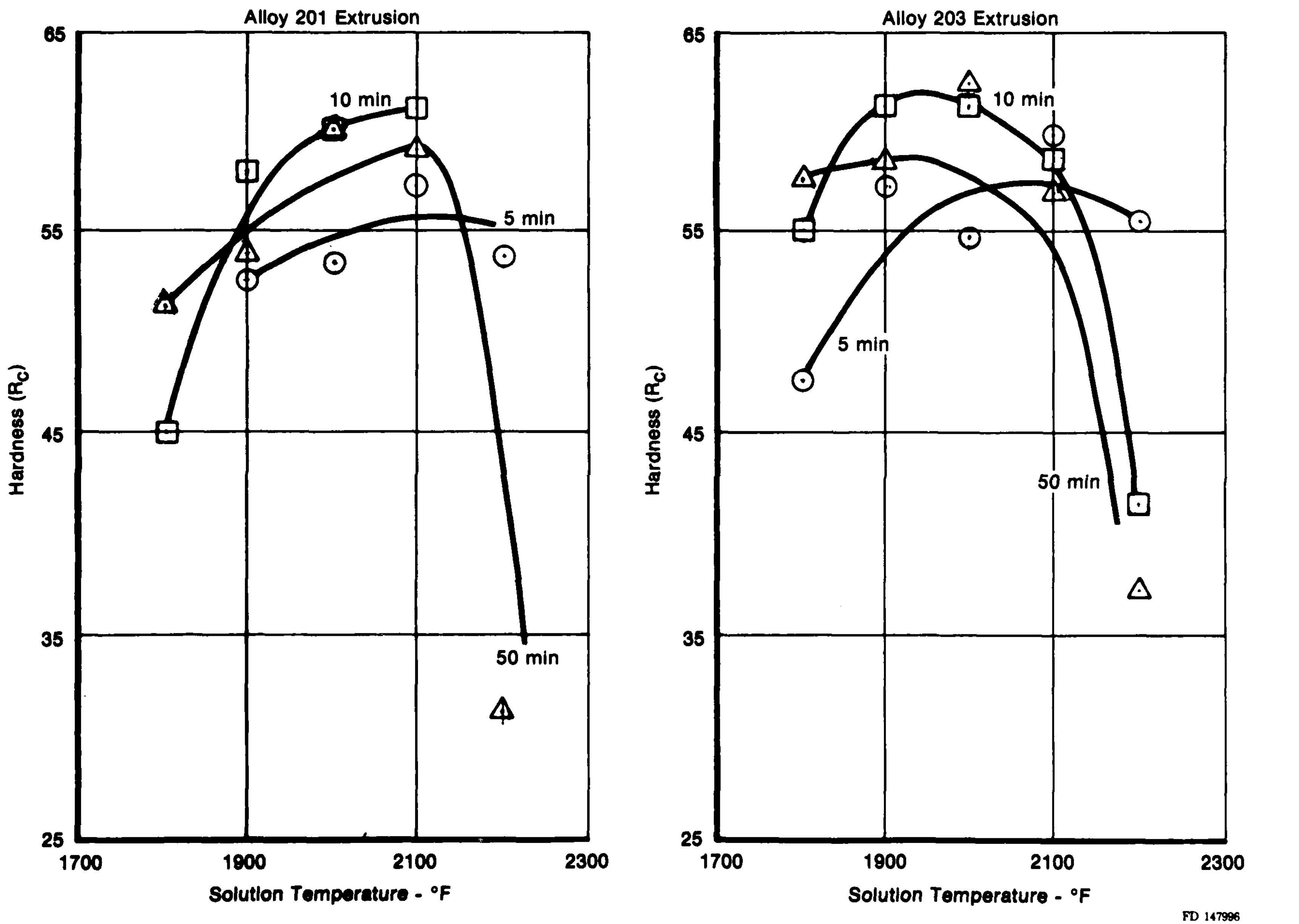
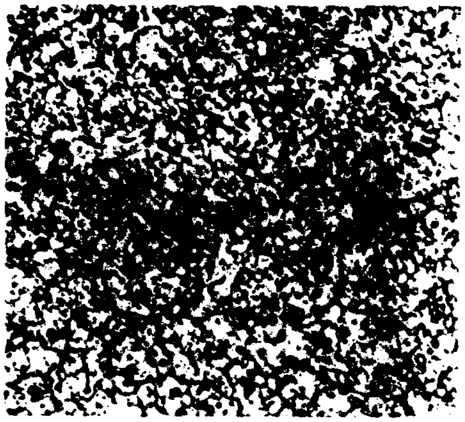


Figure 14. Hardness vs Solution Temperature



FD 147997

Figure 15. Typical Microstructure of Alloy 203C Fully Heat Treated

SECTION VI

ON-GOING STUDY

Twelve aluminum extrusions will be done at AFML using an approximate extrusion ratio of 15:1 at temperatures ranging from 700 to 800°F (371 to 427°C). Microstructural evaluation will begin on this material upon receipt from AFML. Additional aluminum powder conversions will be attempted and the first run of the redesigned high-temperature furnace (steel conversion) will be made. Additional evaluation will be made on both aluminum and iron experimental samples, produced during this report period.

END

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